

## **ITOP 2010 Field Experiment**

Patrick A. Harr

Department of Meteorology  
Naval Postgraduate School  
Monterey, CA 93943-5114

phone: (831) 656-3787 fax: (831) 656-3061 email: [paharr@nps.edu](mailto:paharr@nps.edu)

Russell L. Elsberry

Department of Meteorology  
Naval Postgraduate School  
Monterey, CA 93943-5113

phone: (831) 656-2373 fax: (831) 656-3061 email: [elsberry@nps.edu](mailto:elsberry@nps.edu)

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### **LONG-TERM GOALS**

The long-term goal of this project is to increase understanding of the interaction between the ocean and tropical cyclones over the tropical western North Pacific. Tropical cyclones produce a three-dimensional response of the underlying ocean that includes surface currents, upwelling of the thermocline, and formation of a cold wake. These responses then impact the structure and intensity of the tropical cyclone. Specific objectives are to provide leadership to the ITOP field campaign in support of direct measurements of the ocean and tropical cyclone characteristics.

### **OBJECTIVES**

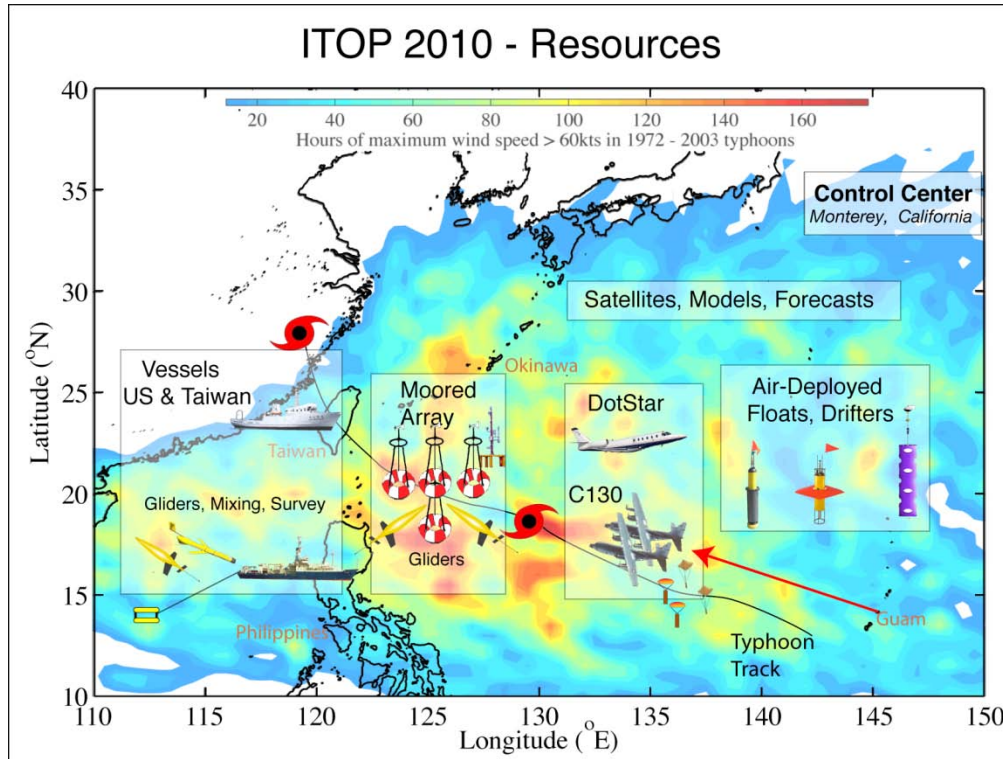
The overall objective of the Office of Naval Research (ONR) Department Research Initiative (DRI) titled Impact of Typhoons on the Ocean in the Pacific (ITOP) is to increase understanding of the ocean response to tropical cyclones over the western North Pacific Ocean. Several specific objectives exist within the overall framework of the DRI. Specific goals include the increase in understanding of the three-dimensional response of the ocean to a tropical cyclone. The sensitivity of the ocean response to varying tropical cyclone characteristics is a critical aspect of this goal. Furthermore, the response of the ocean to the tropical cyclone feeds back onto the tropical cyclone by altering the exchange of heat and momentum between the ocean and the atmosphere.

The specific objectives of this project define the role and support of the Naval Postgraduate School (NPS) faculty and staff during the ITOP field program. During August-September, 2008, the operations center for the Tropical Cyclone Structure-2008 (TCS-08) and THORPEX Pacific-Asian Regional Campaign (T-PARC) field programs was operated from the Meteorology Department of NPS. These programs represented one of the first successful operations of an aircraft-based field program from remotely-located "virtual" operations center. The current project capitalizes on the successes of TCS-08 and T-PARC to support the operations of the ITOP field program

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## APPROACH

The experimental domain is defined to be the western North Pacific with the primary emphasis located in the Philippine and East China Seas (Fig. 1). The observation period occurred between 20 August – 20 October 2010. During this two-month period, the experimental region contained 5 tropical cyclones.



***Fig. 1 Experimental domain and resources utilized during ITOP.***

During ITOP, several deployments of ocean drifters and floats were deployed in the environment of three of the tropical cyclones. During the intensive measurement period, two WC-130J aircraft from the 53<sup>rd</sup> Air Force Reserve Hurricane Hunter Squadron were based in Guam. These aircraft measured the properties of typhoons using onboard sensors and deployed dropwindsondes. These efforts complemented those of the existing DOTSTAR typhoon surveillance program based in Taiwan. The WC-130J aircraft also deployed arrays of floats and drifters in front of three typhoons (TY Fanapi, TY Malakas, and TY Megi) to measure the ocean response. After the passage of TY Fanapi, additional floats and drifters were deployed by a research vessel to survey the wake. Additional gliders and drifters were deployed and previously air-deployed floats and drifters will be recovered. The measurements were guided by satellite-based and model-based estimates of storm location, evolution and structure, ocean surface properties, and the coupled atmosphere-ocean evolution of the typhoons. During the intensive period, operations were directed and coordinated from a control center located at the Naval Postgraduate School in Monterey, California.

## **WORK COMPLETED**

The NPS research team fully participated in the mission planning, daily operations, forecast, and aircraft operations activities, during the ITOP field phase. A forecast and briefing strategy was developed to support the ITOP operations and mission planning for the WC-130J. A communication system was established to allow remote participation by all of the ITOP participants.

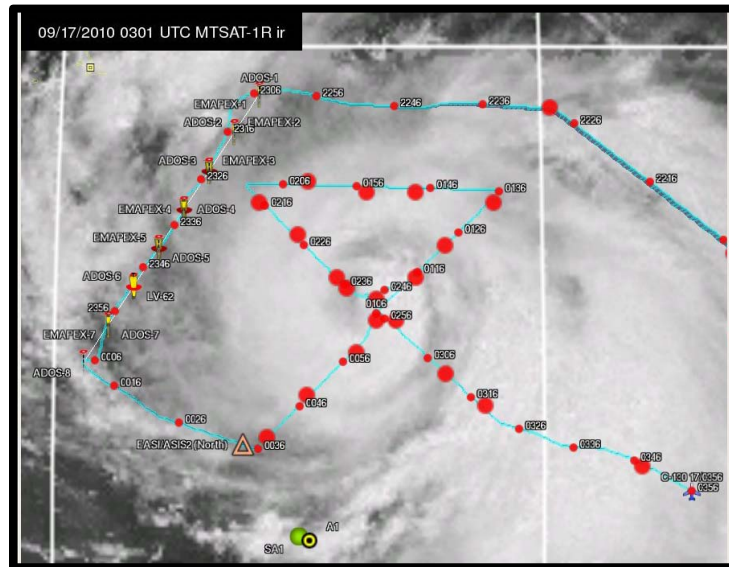
Furthermore, NPS served as the data manager for the observations, analyses, and model forecast data sets that were collected in the ITOP field experiment. Data that were obtained in real time from aircraft operations were transmitted to NPS for archive in a non-quality controlled format. The final quality control data set will be produced by the Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR).

To place the ocean-sensing equipment in the correct location with respect to translating tropical cyclones requires carefully planned flight operations were based on accurate forecasts of tropical cyclone intensity, structure, and motion. Additionally, careful analyses and forecasts of ocean conditions, which included eddy locations and thermal characteristics were produced. Operational forecasts of atmospheric, storm, and ocean conditions were supplied by operational forecasters from the Australian Bureau of Meteorology, Tropical Cyclone Forecast Center, Perth Australia.

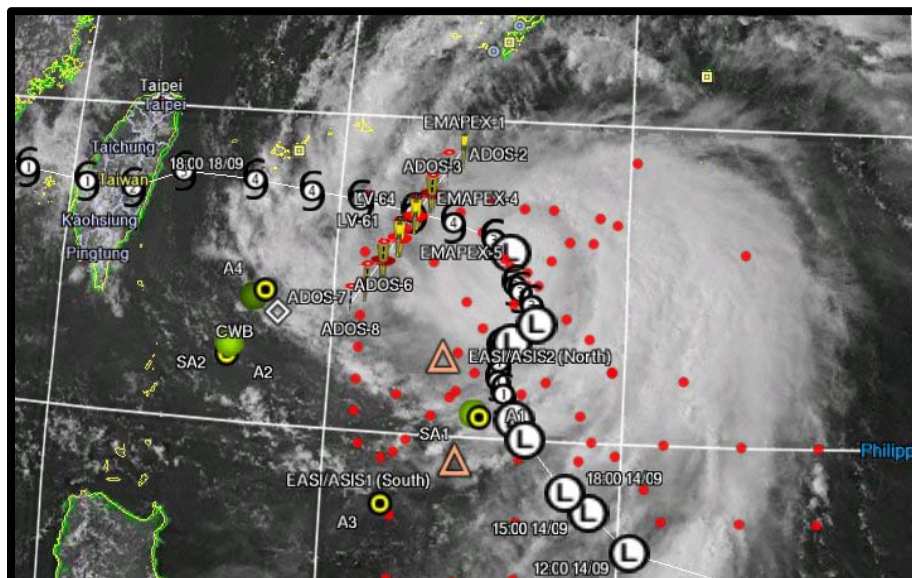
## **RESULTS**

As a result of the ITOP operations, several first-time accomplishments occurred with respect to air-ocean observations in a tropical cyclone environment over the western North Pacific. For the case of TY Fanapi, a series of floats and drifters were layed in a line ahead of the forecast storm track (Fig. 2) near the time that the storm made a sharp turn to the west and began to intensify (Fig. 3). The track of TY Fanapi moved directly across the ocean instrument array at the time that the storm was being observed by the WC-130J and the DOTSTAR aircraft (Fig. 4).

Immediately following TY Fanapi, TY Malakas formed and followed a poleward-oriented track along 140°E. This large storm occurred in a very different atmospheric and oceanic environment than TY Fanapi, which allowed for a fundamentally different measurement strategy. In the case of TY Malakas, a series of ocean drifters were placed behind the storm to measure the characteristics of the ocean wake behind the rapidly-moving storm. A unique sampling strategy was followed to provided for rapid deployments of drowpindsonde and AXBT sensors in the rapidly intensifying TY Malakas. These data provide a detailed observation record that can be used to determine the role of storm structure on the wake characteristics that were subsequently measured by the deployment of the ocean drifters.

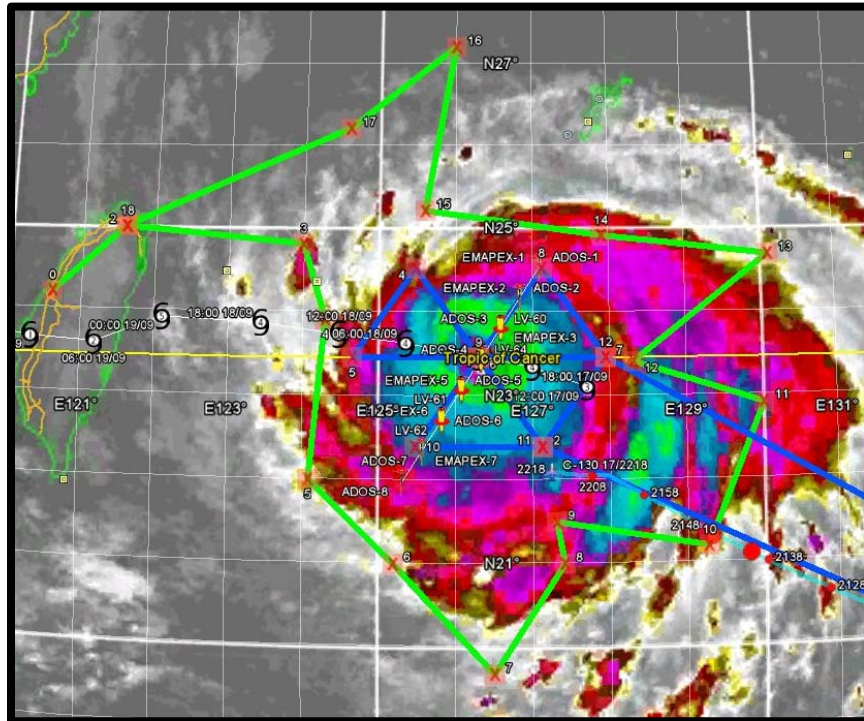


**Fig. 2** *Flight track of the WC-130J (light blue line) overlaid on an infrared MTSAT image at 0301 UTC 17 September 2010. The small red dots define 10-min intervals along the flight track and the large red dots mark locations of dropwindsonde deployments. The locations of the ocean instruments are marked by the various instrument symbols along the line ahead of the storm center.*



**Fig. 3** *Track of TY Fanapi overlaid on a visible MTSAT image at 2315 UTC 17 September 2010. The red dots represent flight-level data reports from the WC-130J and the ocean sensors are marked by representative symbols along the line ahead of the storm center.*



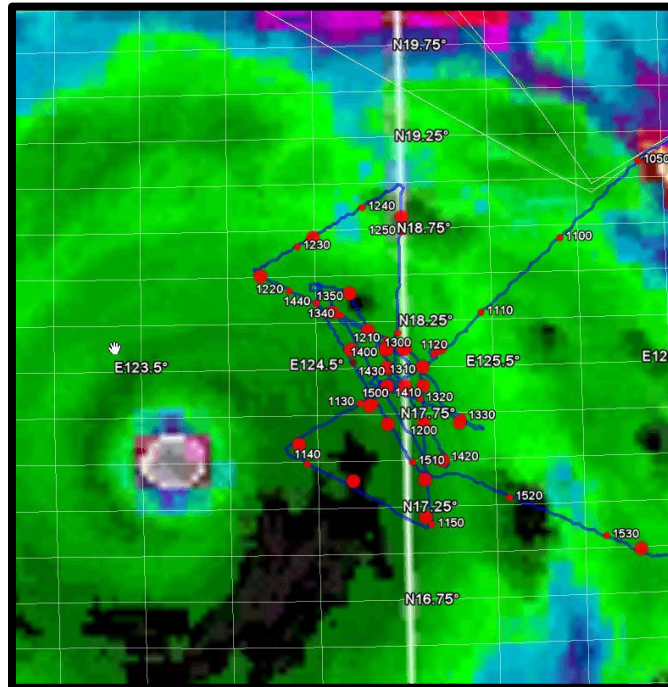


***Fig. 4 Infrared MTSAT imagery at 2210 UTC 17 September 2010 of TY Fanapi as it crosses the ocean instrument array. The WC-130J flight track is defined by the blue line and the DOTSTAR flight track is defined by the green line***

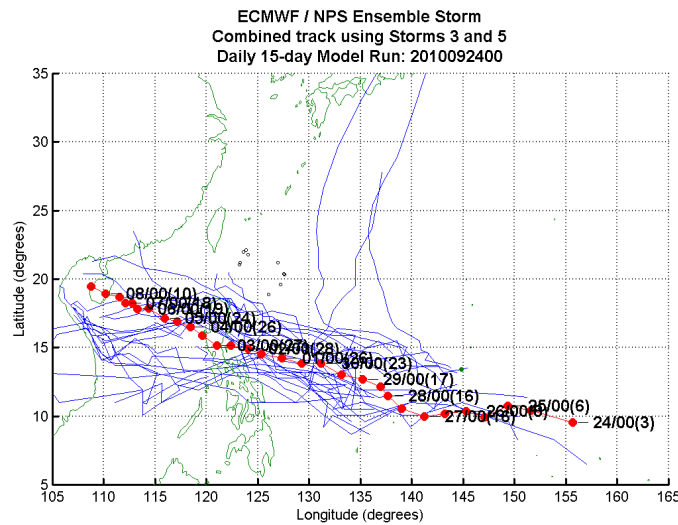
The occurrence of TY Megi at the end of the ITOP field period provided for a unique opportunity to obtain observations of air-ocean interactions in the environment of a super typhoon (maximum winds in excess of 130 kt). A full deployment of ocean floats was made ahead of the track of TY Megi and the storm passed over the instrument array as it was being sampled by the WC-130J aircraft. Perhaps the most unique mission associated with TY Megi was the flight path just beyond the radius of maximum winds in the right-rear quadrant of the storm (Fig. 5). Along the flight path, a rapid deployment sequence of dropwindsondes and AXBT instruments was conducted to provide unique air-ocean observations in the high-wind environment.

Finally, the tropical cyclone tracks produced in the two-week ensemble prediction system from the European Center for Medium-Range Forecasts (ECMWF) were obtained and analyzed for use in ITOP decision-making processes. Individual ensemble members (Fig. 6) were combined into a type of consensus track for one particular storm. Additionally, all storms forecast to occur in a week-long period were displayed (Fig. 7).

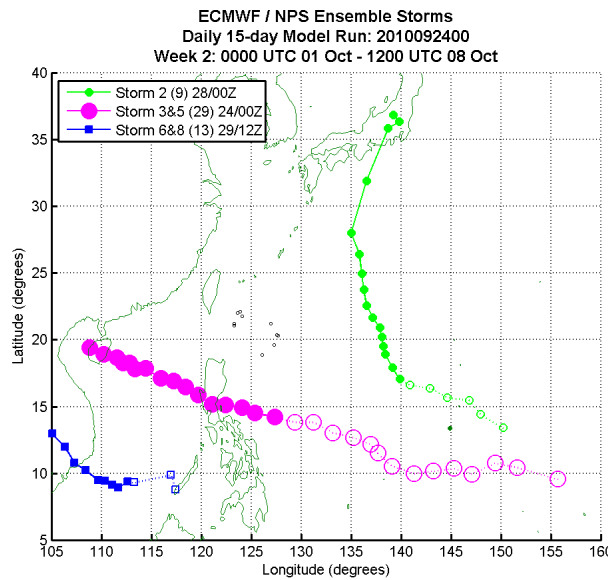
The recent completion of the ITOP field program has provided a unique set of ocean and atmosphere observations in the unique environment of tropical cyclones over the western North Pacific.



**Fig. 5** Enhanced infrared MTSAT imagery at 2110 UTC 17 September 2010. The flight track of the WC-130J is depicted by the blue line. Large red circles mark the locations of coincident deployment of dropwindsondes and AXBTs.



**Fig. 6** Storm tracks contained within individual ensemble member forecasts from the ECMWF two-week ensemble prediction system (light blue lines) initiated at 0000 UTC 24 September 2010. The consensus track is defined by the red track.



***Fig. 7 Consensus tracks produced from individual ECMWF ensemble member forecasts of tropical cyclone activity during the second week of a two-week forecast initiated at 0000 UTC 24 September 2010.***

## IMPACT/APPLICATIONS

The research being conducted on the comprehensive data sets gathered during the ITOP field program will result in increased understanding of air-ocean interaction in the environment of tropical cyclones and increased accuracy associated with the prediction of tropical cyclone characteristics and oceanic responses to tropical cyclone activity.

## TRANSITIONS

Following the compilation and analysis of the wide range of ITOP data sets, research results that identify factors responsible for the variability in air-ocean interactions and their prediction will increase the ability to predict mutual influences on the atmosphere and ocean in the environment of a tropical cyclone. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific.